Agenda

1. Introduction

2. Microwave Interferometry

3. Applications – Railway bridge

4. Conclusions
1. Introduction

✓ Identification of Dynamic Parameters of Structures

✓ Conventional Methods – Accelerometers, Inductive Displacement Sensors, Strain gauges,…

➤ Need to be mounted on the structure

➤ Long installation time

➤ Difficult for inaccessible structures

➤ Attached only at certain points
2. Microwave Interferometry
Radar Basics

- Range of target from radar \( R_0 = \frac{c \cdot T_0}{2} \)
- Range Resolution \( \partial_r = \frac{c \cdot \tau}{2} = \frac{c}{2 \cdot B} \)
- Identify two targets if: \( \Delta t > \tau \iff \Delta d > \partial_r \)

Source: www.idscorporation.com
2. Microwave Interferometry
Stepped Frequency Continuous Wave (SFCW)

✓ Sweeps of N continuous electromagnetic waves at stepwise increasing frequencies

✓ Range resolution (B = 200 MHz) \[ \delta_r = \frac{c}{2 \cdot B} = 0.75m \]
2. Microwave Interferometry

Range bin Profile

Range bins and Intensity

Amplitude of reflected wave
- Depends on reflectivity of the target surface
- Good Reflectors: Concrete edge, Rock
- Poor Reflectors: Vegetation

Phase of reflected wave
- Depends on absolute distance to the object
- Wrapped to $-\pi$ to $+\pi$

Source: www.idscorporation.com
2. Microwave Interferometry
Differential Interferometry

\[ \phi^w = W(\varphi_2 - \varphi_1) \]

\[ \phi^w = \phi_{\text{disp}} + \phi_{\text{atm}} + \phi_{\text{noise}} - 2\pi \cdot n \]

Displacement \(d\)

Noise \(\phi_{\text{noise}}\)

Phase ambiguity \(n\)

Atmospheric phase \(\phi_{\text{atm}}\)

\[ \phi_{\text{disp}} = -\frac{4\pi}{\lambda} d_{\text{los}} \]

\(d \propto \varphi_2 - \varphi_1\)

Source: www.idscorporation.com
2. Microwave Interferometry
Measured Quantities and Devices

IBIS-S
( IDS – Italy)

<table>
<thead>
<tr>
<th></th>
<th>Range Resolution</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,75 m</td>
<td>0,75 m</td>
<td></td>
</tr>
<tr>
<td>0,01 mm</td>
<td></td>
<td>0,01 mm</td>
</tr>
<tr>
<td>1 km</td>
<td></td>
<td>Max. Distance</td>
</tr>
<tr>
<td>Up to 200 Hz</td>
<td></td>
<td>4 km</td>
</tr>
<tr>
<td>17.5 mm</td>
<td></td>
<td>Sampling Rate</td>
</tr>
</tbody>
</table>

FastGBSAR
(Metasensing – The Netherlands)

<table>
<thead>
<tr>
<th></th>
<th>Wavelength (Ku Band)</th>
</tr>
</thead>
<tbody>
<tr>
<td>17.5 mm</td>
<td></td>
</tr>
</tbody>
</table>

0,75 m Range Resolution
0,01 mm Accuracy
1 km Max. Distance
Up to 200 Hz Sampling Rate
17.5 mm Wavelength (Ku Band)
3. Application Examples

Chimney

Noise Protection Wall

Pedestrian Bridge

Steel Hanger

Wind Turbine

Railway Bridge
3. Application Example
Railway Bridge
3. Application Example
Railway Bridge

Setup - Rail Track 1

- L = 16.4 m
- MP 1
- MP 2

Introduction | Microwave Interferometry | Applications | Conclusions
3. Application Example
Railway Bridge

Displacement Time Series at MP1 and MP 2

Comparison of MI Radar and Displacement Sensor
### 3. Application Example

Railway Bridge

Comparison of MI Radar and Displacement Sensor

<table>
<thead>
<tr>
<th>Train Passage</th>
<th>Maximum Displacement [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MI Radar</td>
</tr>
<tr>
<td>MP 1</td>
<td></td>
</tr>
<tr>
<td>1 (IC 14:09)</td>
<td>7,15</td>
</tr>
<tr>
<td>2 (ICE3 14:15)</td>
<td>6,06</td>
</tr>
<tr>
<td>3 (RE 14:18)</td>
<td>7,12</td>
</tr>
<tr>
<td>4 (ICE3 14:27)</td>
<td>7,61</td>
</tr>
<tr>
<td>5 (ICE3 14:31)</td>
<td>7,47</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
</tr>
</tbody>
</table>
| **Standard Deviation** | 0,10
3. Application Example
Railway Bridge

Comparison of Eigen Frequencies
MI Radar - Displacement Sensor - Accelerometer Sensor

Displacement Time Series (MP1)

FFT – MI Sensor

FFT – Acceleration Sensor

FFT – Displacement Sensor

Introduction | Microwave Interferometry | Applications | Conclusions
3. Application Example
Railway Bridge

Comparison of Eigen Frequencies
MI Radar - Displacement Sensor - Accelerometer Sensor

<table>
<thead>
<tr>
<th>Train Passage</th>
<th>Eigen Frequency[Hz]</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MI Radar</td>
<td>Displacement Sensor</td>
<td>Acceleration Sensor</td>
<td>MI Radar</td>
<td>Acceleration Sensor</td>
<td></td>
</tr>
<tr>
<td>1 (IC 14:09)</td>
<td>6,72</td>
<td>6,68</td>
<td>6,72</td>
<td>6,72</td>
<td>6,74</td>
<td></td>
</tr>
<tr>
<td>2 (ICE3 14:15)</td>
<td>6,36</td>
<td>6,46</td>
<td>6,46</td>
<td>6,48</td>
<td>6,52</td>
<td></td>
</tr>
<tr>
<td>3 (RE 14:18)</td>
<td>6,36</td>
<td>6,34</td>
<td>6,37</td>
<td>6,36</td>
<td>6,37</td>
<td></td>
</tr>
<tr>
<td>4 (ICE3 14:27)</td>
<td>6,11</td>
<td>6,08</td>
<td>6,12</td>
<td>6,11</td>
<td>6,12</td>
<td></td>
</tr>
<tr>
<td>5 (ICE3 14:31)</td>
<td>6,11</td>
<td>6,12</td>
<td>6,13</td>
<td>6,11</td>
<td>6,13</td>
<td></td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>6,33</strong></td>
<td><strong>6,34</strong></td>
<td><strong>6,36</strong></td>
<td><strong>6,36</strong></td>
<td><strong>6,38</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Standard Deviation</strong></td>
<td><strong>0,25</strong></td>
<td><strong>0,25</strong></td>
<td><strong>0,25</strong></td>
<td><strong>0,26</strong></td>
<td><strong>0,26</strong></td>
<td></td>
</tr>
</tbody>
</table>
3. Application Example
Railway Bridge

Comparison of Damping Ratios
MI Radar - Displacement Sensor - Accelerometer Sensor

Unfiltered Signal  →  Band Pass Filter  →  Filtered Signal

Damping Ratio:

\[ \zeta = \frac{1}{2\pi \cdot m} \cdot \ln \left( \frac{x_n}{x_{n+m}} \right) \]

<table>
<thead>
<tr>
<th>Sensor Type</th>
<th>Eigen Frequency</th>
<th>Damping Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement Sensor</td>
<td>6.12 Hz</td>
<td>2.76 %</td>
</tr>
<tr>
<td>Acceleration Sensor</td>
<td>6.08 Hz</td>
<td>2.93 %</td>
</tr>
<tr>
<td>MI Sensor</td>
<td>6.11 Hz</td>
<td>2.61 %</td>
</tr>
</tbody>
</table>

16. September 2015   |   TU Darmstadt   |   Jiny Jose Pullamthara, M.Sc.   |   16
### 3. Application Example

#### Railway Bridge

Comparison of Damping Ratios

MI Radar - Displacement Sensor - Accelerometer Sensor

<table>
<thead>
<tr>
<th>Train Passage</th>
<th>Damping Ratio [%]</th>
<th></th>
<th>MP 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MI Radar</td>
<td>Displacement Sensor</td>
<td>Acceleration Sensor</td>
</tr>
<tr>
<td>1 (IC 14:09)</td>
<td>Damping is not seen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 (ICE3 14:15)</td>
<td>2.50</td>
<td>2.39</td>
<td>2.04</td>
</tr>
<tr>
<td>3 (RE 14:18)</td>
<td>2.67</td>
<td>2.53</td>
<td>2.60</td>
</tr>
<tr>
<td>4 (ICE3 14:27)</td>
<td>2.59</td>
<td>2.86</td>
<td>2.63</td>
</tr>
<tr>
<td>5 (ICE3 14:31)</td>
<td>2.53</td>
<td>3.10</td>
<td>2.71</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>2.57</td>
<td>2.72</td>
<td>2.49</td>
</tr>
<tr>
<td><strong>Standard Deviation</strong></td>
<td>0.08</td>
<td>0.32</td>
<td>0.31</td>
</tr>
</tbody>
</table>
4. Conclusion

- **Terrestrial Microwave Interferometry offers**
  - High accuracy and high spatial resolution
  - Remote Sensing method
  - Simultaneous measurement of all points on the structure
  - Measurements during all weather conditions and any time of day
  - Measurements are possible during operation
  - Measurement of inaccessible objects
  - Wide range of applications

- **Terrestrial Microwave Interferometry has limitations when:**
  - Complex structure with multiple reflection points are monitored
  - Structures made of wood, glass, fiber are monitored
  - Very large deformations (> 5mm in 0.005 s) are to be monitored

- Highly accurate and efficient method for measuring and monitoring oscillations and deformations of structures.
- Large potential for structural monitoring applications
- Can be used as an input for parameter identifications in the structural analysis (e.g., IFEM method,...)
Thank you for your attention

For more information or queries: pullamthara@psg.tu-darmstadt.de